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WINTER INJURY
OR
DIE-BACK OF THE WALNUT

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This circular contains an account of studies made throuh several seasons on the so-called "Die-back" or "Winter Injury" of the Persian walnut (*Juglans regia*). In certain districts where walnuts are commercially grown, the trees have suffered greatly from this trouble, and in some cases parts of orchards have died from this cause.

Unfavorable soil or climatic conditions which would show little or no effect upon many species of orchard trees, may seriously injure, if not actually kill, a walnut tree. The effect of such unfavorable conditions is often first clearly manifested in the early spring. At that time the tops of healthy trees make rapid growth, whereas the tops of injured trees show no growth whatever. Frequently unfavorable conditions not only cause the death of the uppermost twigs but also of some of the older branches.

"Winter Injury" is a term frequently applied to several conditions, the effects of which are particularly evident in the early spring. Usually "Winter Injury" is most clearly manifested by the death of the young twigs and small limbs and hence is frequently known as "Die-back." These terms will be considered as synonymous in the following discussion.

Winter injury may be considered as the final effect of one or more conditions which are adverse to the normal growth of walnut trees and which eventually cause them to die back in the tops. The following are the most common causes of winter injury: (1) Early autumn frosts, (2) winter drought, (3) high water-table, and (4) alkali soil.

[1] The writers are pleased to acknowledge the assistance given by Mr. D. C. Wylie of the Field Department of the California Walnut Growers' Association and by Mr. E. E. Thomas of the Citrus Experiment Station.

1. *Early autumn frosts.*—Young trees are more likely to suffer from early frosts than are mature bearing trees because the latter go into a dormant condition earlier in the season. Walnut foliage which is still green and shows no sign of its normal autumn color, is apparently as subject to frost injury as are tender vegetables. Such injured foliage drops prematurely, and hence the green, immature twigs are fully exposed to the sun's heat during bright days in fall and winter. The moisture loss, following the dropping of the leaves, is much more rapid from the succulent twigs than from the more mature growth.

In many cases the twigs themselves are not actually injured by the frost, but are killed by sunburning following the loss of the leaves. This is substantiated by the fact that such twigs usually begin to show injury from sunburning about the middle of January. By early spring, more or less of the new growth is dead. In occasional instances, however, a portion of the north side of twigs thus injured may remain healthy and produce normal growth in the following spring. The death of the immature twigs is due not so much to the initial low temperature which killed the leaves as to the subsequent sunburning of the exposed bark. Vertical young shoots frequently show discolorations due to sunburn on the south side over their entire length, while horizontal or oblique branches usually show this sunburned area more strikingly on their upper sides. Such a sunburned appearance of the young limbs in the spring is a prevailing characteristic of trees which have been only mildly frosted the previous fall before the dormant period set in. In as much as the root systems are not injured by this condition, such frosted and sunburned trees, as a general rule, produce a rank, succulent twig growth the summer following the initial injury. Such growth in turn is less likely to mature early and more likely to be injured by autumn frosts than the normal tree. When the cycle of events just described becomes established, it thus tends to perpetuate itself.

If the trees are kept thoroughly covered with whitewash during the winter months, the injury resulting from sunburn may be somewhat reduced. Such a treatment tends to maintain a lower temperature within the twigs. Too much reliance should not be placed upon this treatment, for it has been observed that at best it affords only partial protection. As a general rule it has been observed that frost injury to the foliage of immature twigs, is practically certain to be followed by die-back to some extent, in spite of any remedy known to the writers at the present time.

The coincidence of frosted foliage and subsequent die-back in a five-year-old grove is shown by Chart I. The new wood on these trees was nearly mature when the first frost occurred in November, 1918. The observations on die-back were made in May, 1919. The majority of the trees that had been frosted showed die-back injury;

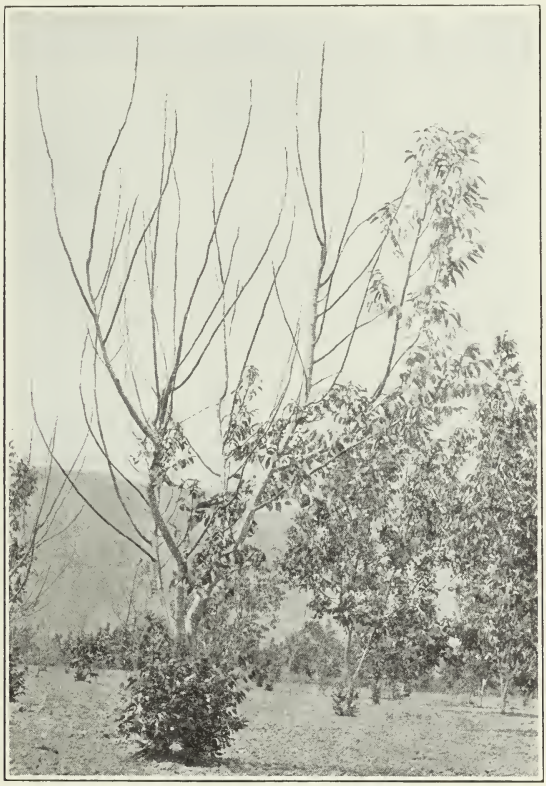

Fig. 1.—A walnut tree injured by frost the preceding autumn. The orchard has had excellent care but is located on low ground.

none were frosted without subsequent die-back. Two trees which were not affected by the first frost still showed a slight injury from die-back. In a few cases, however, it was very apparent from the blackened condition of the twigs, especially the tips, that the wood had been actually killed by the frost at the time of the foliage injury. In such instances as the last it is clear that remedial measures will be of no avail.

Figure 1 shows a walnut tree grown under apparently good environmental conditions in all respects, except that the orchard site

is on low ground and the trees are injured by frost before the wood matures in the autumn. The healthy condition of the roots is manifested by the abundant growth of suckers from the root-stock.

Chart I.—The Relation Between Autumn Frost Injury and Die-Back in a Five-Year-Old Walnut Grove

10	9	8	7	6	5	4	3	2	1
×	×	×	×	×	o	o	×	–	o
×	×	×	×	×	–	o	×	×	×
×	×	×	×	×	×	×	×	×	o
×	×	×	×	×	×	×	×	o	×
×	×	×	×	o	×	o	o	o	×
×	×	×	×	×	o	–	–	×	×
×	×	×	×	×	×	×	×	×	o

Die-back trees, –; normal trees, o; trees showing both frost injury and die-back, ×.

Injury from frost may be prevented if it is possible to mature the young walnut trees early in the autumn so that the leaves will turn yellow and normally fall from the tree before the first early frosts which usually occur from the 1st to the 15th of November, in many of the lowlands in southern California. Early maturity can be promoted by withholding irrigation water in the late summer and early fall. Trees which are not irrigated after August 15th may be expected to mature earlier than trees watered in late August and September. Whenever the soil moisture is abundant in the autumn, due either to heavy summer irrigation or to a high water-table, the trees will continue their growth so late as to be injured by autumn frosts. A high water-table and a frosty orchard site make winter injury a practical certainty. It is doubtful if walnuts can ever be successfully grown on such lands. Figure 2 shows a walnut tree growing in a rich, deep, sub-irrigated soil in a frosty location.

2. *Winter drought.*—We have very convincing evidence to show that trees which enter the dormant period in the fall in a perfectly normal and healthy condition may suffer from die-back due primarily

to a lack of sufficient soil moisture during the winter months (fig. 3). During the winter, trees give off moisture through the limbs and twigs. If for a prolonged period there is not enough soil moisture available to the roots, the trees are unable to obtain sufficient water to offset the loss by evaporation from the branches. In that case

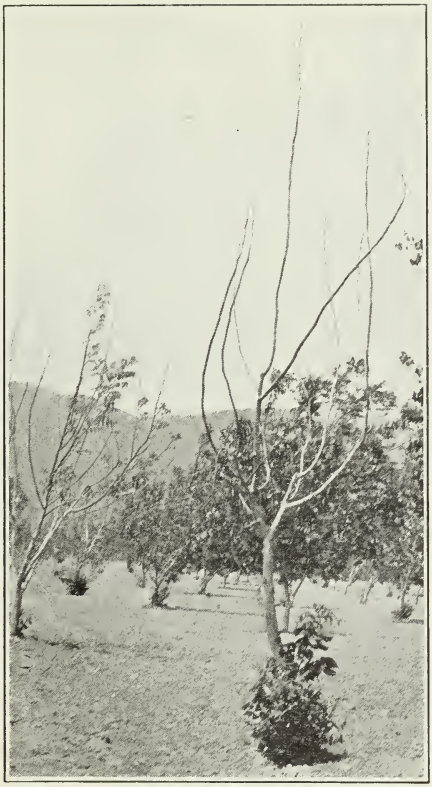

Fig. 2.—A walnut tree growing in a rich, deep, sub-irrigated soil in a frosty location. The new growth continued to grow very late and was killed by frost.

young branches, the thin bark of which permits rapid loss of water from the wood, may die as a result of desiccation. This injury is first evident when such branches fail to produce new growth the following spring.

It is usually not difficult to distinguish between the injuries caused by autumn frosts and by winter drought. Frost injury is usually confined to one or two-year-old wood, but winter drought may kill back limbs eight years old. Winter sunburning is more common on

shoots killed by autumn frosts than on those killed by winter drought, though the sunburned areas may not be clearly defined until January.

The principal contributing factors which bring about such a condition are dry winters and the lack of winter irrigation. Under such conditions the soil may have little or no moisture available for

Fig. 3.—A tree killed back two consecutive years by winter drought.

the tree roots below the surface foot and even this zone does not contain an optimum amount of moisture until mid-season of the winter rainy period.

The winter of 1917–18 was followed by a great deal of die-back injury to bearing walnut trees. An examination of walnut orchards during this winter showed that most of the soils were very dry. In several cases in orchards which subsequently showed die-back injury, the moisture in the first four feet of soil was below the wilting point

until late winter. Thus the roots were unable to acquire sufficient moisture to replenish the loss from the trees and consequently the tips were killed by excessive desiccation.

The result of this winter drought can be judged by figure 4, which is a general view in a grove showing the effect of die-back in May, 1918. During the fall of 1918 the dead wood in these trees was removed and the grove was thoroughly irrigated during the latter part of November. Figures 5 and 6 show the same trees in November, 1918, and July, 1919, respectively. The trees are fast recovering from the winter injury and were killed back only slightly during the winter of 1918–19

Fig. 4.—A general view in a grove which suffered from drought during the winter of 1917–18. Photo taken in May, 1918.

following the irrigation. The trees which were the most severely injured the previous year and thus produced sucker growth from six to ten feet long, died back at the tips during 1918–19. Such excessive growth was very immature as late as December, 1918, while the succulent foliage on the tips had been frosted early in November.

We have found that winter-injured trees are more susceptible to die-back the year following the initial injury, than are normal trees. The increased susceptibility of injured trees is inevitable because of the succulent nature of much of the young growth produced. In the summer following the first "Die-back," the amount of living wood is small in comparison with the root system, and is forced into very active growth. The type of growth produced is therefore similar to that following a severe pruning of the tree.

The majority of the trees in the Steinburg grove (Hemet, Calif.) leafed out nearly to the tips of the twigs in the spring of 1919, follow-

ing the winter irrigation. Figures 7, 8, and 9 show a typical badly injured tree in this grove, and the stages in its subsequent recovery as a result of the winter irrigation. The pictures were taken May 23,

Fig. 5

Fig. 6

Figs. 5 and 6.—Pictures of the same orchard shown in fig. 4. General view taken in November, 1918, and July, 1919, respectively.

1918, November 20, 1918, and August 13, 1919, respectively. The dead wood seen in figures 7 and 8 was removed from the trees after photographing it in November, 1918. From the results it will be seen that the wood which went into the winter in healthy condition came

through without injury while in the absence of winter irrigation it would undoubtedly have gone back to the condition shown in figure 7.

Winter injury as illustrated above, which is apparently traceable to lack of sufficient soil mosture, can often be seen in groves which are not irrigated after the walnut harvest season. Frequently such groves show a direct relationship between the distribution of the injured trees and the available soil moisture during the winter season. Cases of this class may be clearly exemplified by the O. W. Morrow grove

Fig. 7.—A typical badly injured tree in the Steinburg grove. Picture taken May 23, 1918.

of Hemet. This grove received no irrigation after October, 1918. A small quantity of water was used (37.5 miners' inches per ten acres for 24 hours) and was applied in furrows uniformly spaced three feet apart. Since the irrigation furrows were 600 feet long it is evident that the lower part of the orchard did not receive sufficient water during the twenty-four hours' run, though the upper portion was fairly well watered. This irregular distribution of water was evident as late as May 15, 1919 (before the next irrigation season began). It should be noted that the moisture in the soil at such a time consists of that left over from preceding irrigations plus that which has

accumulated from the winter rains. Our determinations showed that there was a marked difference in the amounts of moisture in the upper and lower parts of this grove. In the upper part of the grove the soil was moist to a depth of five to six feet, while in the lower part of the grove the moisture did not extend much below three feet from the surface.[2]

The relation between soil moisture and winter injury can be seen at a glance in the orchard and is illustrated by Chart 1. For con-

Fig. 8.—The same tree shown in fig. 7. Picture taken November 20, 1918. The dead wood was removed from the tree after photographing.

venience in observing the winter-injury in this orchard, we have divided the trees into three classes: first, trees not winter-killed; second, trees slightly winter killed, and third, trees badly winter-killed. Reference to Chart 2 shows that the winter injury was greatest in the

[2] By the use of a soil tube the penetration of the winter rains or of irrigation water can easily be determined. The subsoils of this district in the Hemet valley are free from any ground water for many feet from the surface and are characterized by their ability to be reduced by native vegetation or orchard trees, to a characteristic dryness easily recognized. This dryness approaches close to the hygroscopic coefficient throughout the subsoils at the end of each growing season. In strata below the reach of irrigation water or rainfall, the subsoil may remain permanently in this dry condition.

lower section of the grove, less in the middle section, and least in the upper section. The two tree-rows in this orchard below the lower section show less injury than the section just above them, due apparently to the fact that no waste water is allowed to run off this orchard, but is held by a dike and thus the lower two rows get an extra amount of water.[3]

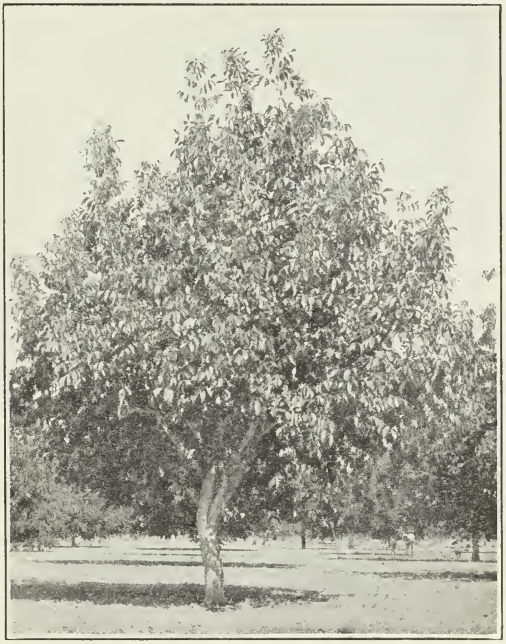

Fig. 9.—Same tree as shown in figs. 7 and 8. Picture taken August 13, 1919. The picture shows that the tree made an almost complete recovery following winter irrigation.

The actual number of trees injured in each section was as follows:

	No injury	slight injury	Badly injured
Upper section	48	4	0
Middle section	12	26	14
Lower section*	1	16	34

* One tree is missing in this section.

This distribution and the fact that it cannot be due to chance, is clearly set forth by the diagram. A soil survey of this orchard shows no appreciable difference in the surface soil or subsoil types within

[3] This orchard has been normally irrigated at the rate of only 1.8 acre inches per irrigation per month from May to October.

seven feet of the surface. This and other examples which have been studied, point clearly to a lack of soil moisture as the important factor in causing winter injury of the walnut trees in this and many other orchards.

CHART 2.—DISTRIBUTION OF WINTER-KILLED TREES, O. W. MORROW GROVE, HEMET, MAY 15, 1919

	IRRIGATION FLUME													
Upper section	o	o	o	o	o	o	o	o	o	o	o	o	o	
	o	o	o	o	o	o	o	o	o	o	o	o	o	
	o	o	o	o	o	o	o	o	o	o	o	o	o	
	o	×	o	o	o	×	o	×	×	o	o	o	o	
Middle section	o	×	×	×	×	o	×	×	×	o	×	×	o	
	o	o	×	×	o	×	×	×	o	o	×	×	×	
	o	*	×	×	×	*	×	*	o	o	*	*	*	HIGHWAY
	×	*	*	*	*	×	×	*	*	×	×	*	*	
Lower section	×	×	*	×		*	×	*	*	*	o	*	*	
	×	×	*	×	*	*	*	*	×	×	×	*	*	
	×	*	×	×	*	*	*	*	*	×	*	*	*	
	*	*	×	×	*	*	*	*	*	*	*	*	*	
	o	×	×	×	*	*	×	*	*	×	*	*	×	
	o	o	*	×	×	*	o	o	×	o	×	*	o	
	HIGHWAY													

o, trees not winter-killed; ×, trees slightly winter-killed; *, trees badly winter-killed.

In view of results such as those presented in the foregoing pages it seems evident that it is not difficult to prevent this type of die-back, or winter injury, due to winter drought. The application of sufficient irrigation water to reach the tree roots soon after the harvest season will tend to prevent such injuries. The grower should use a soil tube,

or a soil auger, in the autumn to determine whether the soil to a depth of five feet contains enough moisture for the welfare of the tree during the winter. The regular practice of fall irrigation in walnut groves may be considered as a profitable form of insurance since it is impossible to predict the occurrence or the volume of winter rains. We know that frequently the rains are too late and insufficient for the welfare of walnut groves. It goes without saying that trees on a light

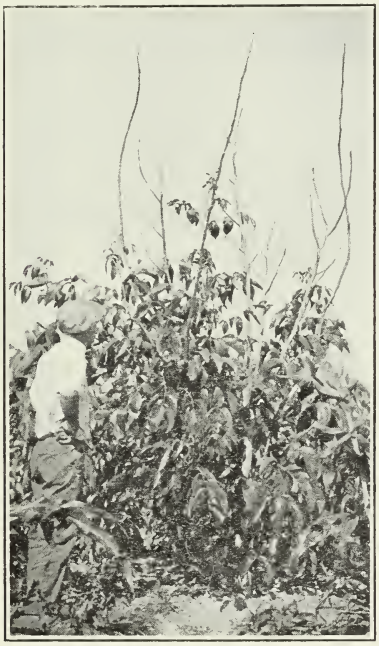

Fig. 10.—Shows winter drought injury in a Tustin grove photographed July 30, 1919. The soil moisture in this grove was reduced in the preceding fall by the inter-crops. The trees were badly injured before the winter rains occurred.

sandy type of soil are in greater danger of injury from winter drought than are trees on a heavier type of soil. In addition to soil types there are other factors involved in the production of winter injury, such as, the character of the rainfall, the rate and amount of evaporation, temperature, etc.

The growth of a winter inter-crop such as barley, during a normal season may bring about the same adverse soil moisture condition that the dry winter does, unless great care is taken to apply enough water for the needs of both trees and inter-crop. For example, if the barley is considered, the soil may become excessively dry about the time

that the hay is maturing, which is the time the walnuts should be starting into active growth.

Unless fall irrigation is practiced the growth of summer inter-crops between the walnut trees may be conducive to winter injury of the trees. This is due to the fact that the moisture is reduced to such an extent at the end of the growing season that the trees are injured before the winter rains occur. Such a case is well shown by an orchard of three-year-old walnuts in Tustin which was interplanted to peppers (fig. 10). The peppers and trees were last irrigated August 28, 1918. There were no early fall frosts to complicate the case, as shown by the fact that peppers were harvested as late as November 15 in this grove. In the spring of 1919 the majority of the trees showed serious winter injury throughout the tops. Without question, the soil moisture during practically the entire dormant period of the trees was considerably below the wilting point, except in the surface foot of soil. The winter rains of 6.97 inches which fell in small intermittent amounts, penetrated the soil in nearby bean fields to the extent of only twelve to eighteen inches at the end of the rainy season.

The same results are often found where beans have been grown as an intercrop. Water is withheld from such groves during the latter part of the summer in order to ripen the beans. After the beans are harvested the soil of the grove is usually very dry. This condition may be of benefit to the walnut trees because it insures a state of maturity which will bring them through the winter in good condition. In such cases, however, winter irrigation is usually necessary and should be applied soon after the leaves fall from the walnut trees.

3. *High water-table.*—A high water-table may be a contributing factor to the die-back of walnuts. When such a condition exists it is usually impossible to bring about the early maturity of the walnut trees by withholding the late summer and fall irrigations.

In the presence of a high, more or less stationary water table, the twigs and foliage, especially on young trees, usually remain green and succulent until December, unless killed earlier by frosts.

Another condition which is equally critical and as apt to injure bearing trees, as well as young ones, is the occurrence of a fluctuating water-table. The sudden rise of a fluctuating water-table kills that portion of the root system which is located in the saturated stratum. In severe cases where the major portion of the root system is killed the twigs and young limbs of the tree later exhibit typical cases of "Die-back." It might seem paradoxical that the top of the tree should dry out and die when the roots stand in an excessively wet soil, but there is nothing contradictory in the situation when it is seen

that the death of the major portion of the roots makes it impossible for the top to receive the necessary moisture to sustain life.

Figure 11 shows a tree in the Elsinore Valley where the water-table suddenly rose during the spring of 1916 following heavy rains and cloud bursts the previous winter in the adjacent mountains. During the entire summer of 1916 the ground water in this grove

Fig. 11.—A tree in the Elsinore Valley showing "Die-back" caused by a sudden rise of the water-table.

was only one to three feet from the surface, and at certain spots in the grove springs suddenly appeared from which water flowed during the entire summer. The water in the well on this grove rose meanwhile, from a depth of twenty feet to the surface of the ground. The water was found to be relatively free from alkali, therefore this injury may be ascribed mainly to drowning of the root system and should not be confused with a high water-table accompanied by alkali salts, which will be considered later.

Trees which have been injured by an excess of water do not show the power of recovery that the drought-stricken trees show. In the former case the major portion of the roots has been killed, while in the latter case the roots are not seriously injured. Although this picture was taken nearly two years after the rise in ground water and after the water-table had fallen to twelve feet below the surface,

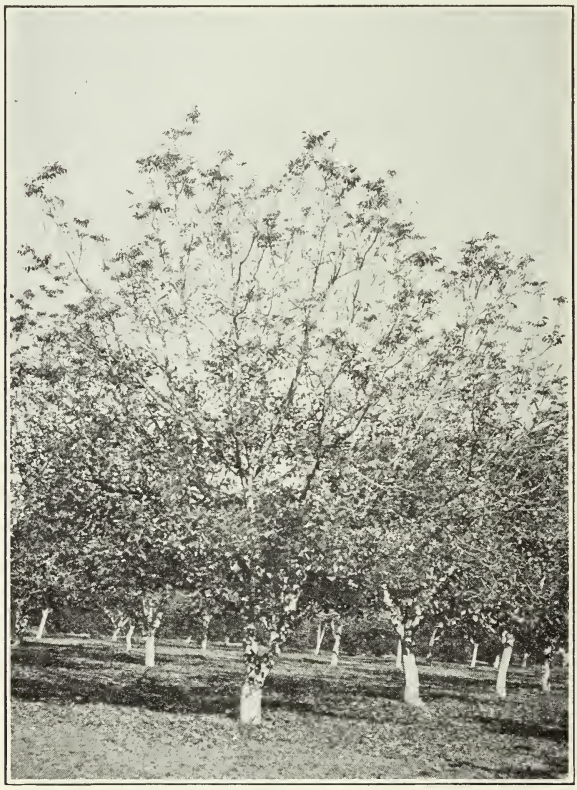

Fig. 12.—An alkali-injured tree which shed the majority of its foliage in early September and then leafed out again, especially at the terminal buds, and was in bloom November 8, 1918.

the tree was not sending out the new growth from the top or the root stock which would characteristically follow frost or drought-injured trees. The year this picture was taken, the soil conditions in this grove were favorable to the growth of walnut trees, yet the tree was barely holding its own and in no sense recovering.

Instances of this kind are comparatively rare as the prime cause of die-back in walnuts, but they are occasionally encountered on lands

subject to overflow. Trees were injured in the Garden Grove section following the surface flooding of 1916 during the same period that the Elsinore trees were nearly killed by excessive sub-irrigation.

4. *Alkali injury.*—Alkali injury is characteristic and may result in the death of the walnut tree. On a soil which contains alkali in harmful amounts, the edges of the leaves of walnut trees are often

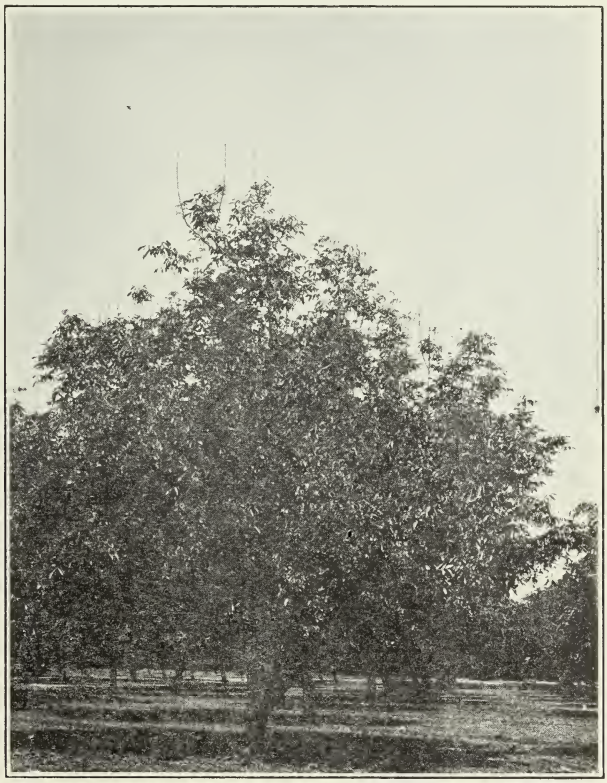

Fig. 13.—A tree in the same orchard as the one shown in fig. 12. Photographed in June, 1919.

burned. This condition may often be seen as early as June or July and is followed by the shedding of the leaves in August and early September. The sudden and premature exposure of the twigs and limbs to the hot fall sunlight through the premature shedding of the leaves may cause severe sunburning. In such cases also the terminal portion of the twigs put forth a new crop of leaves in October which grow until killed by winter frosts. As in the typical frost injury, the twigs sunburn during the winter and much of the current year's

growth dies back. Figure 12 shows a walnut tree which shed the majority of its foliage in early September and then leafed out again, especially at the terminal buds, and was in bloom November 8, when the picture was taken. The injury the following year to this late growth is shown in figure 13, which shows the condition in June, 1919,

Fig. 14.—Two roadside trees, both of which are watered by surplus water from adjacent orange groves; the trees on the right receive alkali well water and those on the left receive a good quality river water.

of a tree in the same orchard as the one noted above. The relation of the injury to the salt content of the soil may be seen from the following analysis of soil samples taken from this grove.

		Parts per million										
Ft.	Total solids	SiO_2	SO_4	Ca	Na	Mg	K	PO_4	CO_3	HCO_3	Cl	NO_3
1	1180	91	400	115	145	30	38	43	0	183	124	40
2	1255	109	380	132	145	35	20	51	0	122	106.4	7
3	1430	151	560	240	97	45	15	14	0	244	124	6
4	1410	130	530	249	83	40	18	14	0	320	142	trace
	5275											

Samples of soil taken on the same day from an adjoining grove show the presence of only 2875 parts per million of salts, in contrast to 5275 found in the grove where the trees showed alkali injury. The difference in the salt content of these soils is primarily due to the quality of irrigation water used. The good grove has been irrigated with river water of good quality, while the poor grove has been irrigated with well water which is known to contain relatively large

amounts of soluble material. (A discussion of the quality of irrigation waters and of their effects on soils will be found in a forthcoming Bulletin of the University of California, College of Agriculture.)

The effect of alkali irrigation water on walnut trees is seen in figure 14, which shows two roadside trees, both of which receive surplus water from adjacent orange groves. The trees on the right receive alkali (1342 parts per million) well water and those on the left receive a good quality river water.

In extreme cases of alkali injury, the whole tree dies after having suffered increasing injury for several years.

SUMMARY

Winter injury or die-back of walnuts is characterized by a sudden death of the tops of the trees. Such injury is usually first noticeable during the early spring following the dormant period.

The most common causes of the winter injury or die-back are:

1. Early autumn frosts kill the immature, growing shoots. Young walnut trees are more subject to injury from this cause than older trees, because the former are usually later in maturing their new wood. Such frosts cause the foliage to drop prematurely and injure the growing tips of the twigs. The denuded twigs are subject to further injury from subsequent fall and winter sunburn. The presence or extent of this injury is usually overlooked until the following spring.

To reduce the danger from autumn frosts it is advisable to withhold the late summer irrigation in order to promote the early maturity of the trees.

2. Winter drought causes die-back in either young or bearing walnut groves. Trees suffering from this condition fail to make new growth in the spring, except from the trunks or main limbs. The new growth on such trees has lost so much water during the winter that the buds are unable to develop in spring. The cause of the die-back has been found to be due to an extremely low moisture content of the soil during a large part of the winter. Under such conditions the water lost from the young shoots during the winter cannot be replenished by the root system. Under such conditions the shoots die from desiccation.

Fall and winter irrigation of the walnut groves has been found to eliminate the injury from winter drought. The amount of irrigation will depend upon the type of soil, the amount of soil moisture

present at the end of the harvest season, and the system of intercropping used.

3. A high water-table may be a contributing factor in killing walnut trees. A permanently high water-table causes the trees to prolong their growing season, with the result that they are killed by frosts. The sudden rise of a fluctuating water-table may kill a large part of the root system and produce a typical die-back in the tops, even though the wood is mature.

4. Alkali soils containing such a high salt content as to injure the root systems of walnut trees, also cause the tops of the trees to die back in response to the root injury. In the initial stages of alkali injury the leaves turn brown at the margin and fall prematurely. The denuded shoots sometimes put out a new set of leaves in the fall. The top of the trees gradually dies back until the entire tree is lost.

The recovery of alkali-injured trees has never been noted by the writers. If injury is being caused by the use of irrigation water containing too much alkali evidently the use of such water should be discontinued.